

AD-A103 410

DSC ELECTRICAL CONDUCTIVITY AND NMR STUDIES OF SALT  
PRECIPITATION IN PPO C. (U) HUNTER COLL NEW YORK DEPT  
OF PHYSICS AND ASTRONOMY J J FONTANELLA ET AL.

1/1

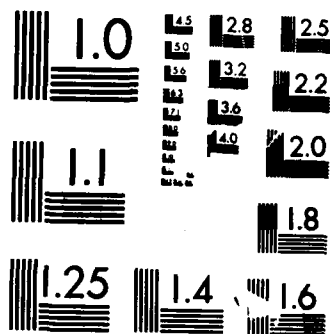
UNCLASSIFIED

01 JUL 87 TR-27 N00014-87-AF-00001

F/G 7/4

NL





MICROCOPY RESOLUTION TEST CHART  
NATIONAL BUREAU OF STANDARDS-1963-A

AD-A183 410

OFFICE OF NAVAL RESEARCH

Contract N00014-87-AF-00001

R&amp;T Code 413d001—02

Technical Report No. 27

DSC, Electrical Conductivity, and NMR Studies of  
Salt Precipitation in PPO Complexes

by

John J. Fontanella &amp; Mary C. Wintersgill

Prepared for Publication

in the

British Polymer Journal

U. S. Naval Academy  
Department of Physics  
Annapolis, MD 21402-5026

July 1, 1987

DTIC  
ELECTE  
JUL 27 1987  
S D  
E

Reproduction in whole or in part is permitted for  
any purpose of the United States Government

\* This document has been approved for public release  
and sale; its distribution is unlimited

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE

## REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION <b>Unclassified</b>		1b. RESTRICTIVE MARKINGS	
2a. SECURITY CLASSIFICATION AUTHORITY		3. DISTRIBUTION / AVAILABILITY OF REPORT This document has been approved for public release and sale; its distribution is unlimited.	
2b. DECLASSIFICATION / DOWNGRADING SCHEDULE		5. MONITORING ORGANIZATION REPORT NUMBER(S)	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) <b>27</b>		7a. NAME OF MONITORING ORGANIZATION	
6a. NAME OF PERFORMING ORGANIZATION <b>U. S. Naval Academy</b>	6b. OFFICE SYMBOL (if applicable)	7b. ADDRESS (City, State, and ZIP Code)	
6c. ADDRESS (City, State, and ZIP Code) <b>Physics Department Annapolis, MD 21402-5026</b>		9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER	
8a. NAME OF FUNDING / SPONSORING ORGANIZATION <b>Office of Naval Research</b>	8b. OFFICE SYMBOL (if applicable)	10. SOURCE OF FUNDING NUMBERS	
8c. ADDRESS (City, State, and ZIP Code) <b>800 N. Quincy Street Arlington, VA 22217-5000</b>		PROGRAM ELEMENT NO. <b>61153N</b>	PROJECT NO. <b>RR013-06-0C</b>
		TASK NO. <b>627-793</b>	WORK UNIT ACCESSION NO.
11. TITLE (Include Security Classification) <b>DSC, Electrical Conductivity, and NMR Studies of Salt Precipitation in PPO Complexes (Unclassified)</b>			
12. PERSONAL AUTHOR(S) <b>John J. Fontanella and Mary C. Wintersgill</b>			
13a. TYPE OF REPORT <b>Interim</b>	13b. TIME COVERED FROM <b>86/10/1</b> TO <b>87/9/30</b>	14. DATE OF REPORT (Year, Month, Day) <b>1987 July 1</b>	15. PAGE COUNT <b>16</b>
16. SUPPLEMENTARY NOTATION			
17. COSATI CODES		18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)	
FIELD	GROUP	SUBGROUP	
		Prepared for publication in the British Polymer Journal	
19. ABSTRACT (Continue on reverse if necessary and identify by block number) DSC and electrical conductivity measurements of PPO complexed with <b>NaI</b> and <b>KSCN</b> are reported. In addition, 23 NMR measurements of PPO8NaI, both at ambient and elevated pressure (2.0 kbar) have been performed. The DSC data clearly indicate that the salt precipitates out of the complexes at about 85° for NaI and 60°C for KSCN. These effects are manifested by a dramatic departure of the conductivity from VTF behavior, and a relatively sharp drop in mobile Na concentration deduced from NMR measurements at somewhat elevated temperature (about 80°C). High pressure NMR linewidth measurements are consistent with a pressure-induced increase in the glass transition temperature.			
20. DISTRIBUTION / AVAILABILITY OF ABSTRACT <input checked="" type="checkbox"/> UNCLASSIFIED/UNLIMITED <input type="checkbox"/> SAME AS RPT <input type="checkbox"/> DTIC USERS		21. ABSTRACT SECURITY CLASSIFICATION <b>Unclassified</b>	
22a. NAME OF RESPONSIBLE INDIVIDUAL <b>John J. Fontanella</b>		22b. TELEPHONE (Include Area Code) <b>301-267-3487</b>	22c. OFFICE SYMBOL

DSC, Electrical Conductivity, and NMR Studies  
of Salt Precipitation Effects in PPO Complexes

Mary C. Wintersgill and John J. Fontanella

Physics Department  
U.S. Naval Academy  
Annapolis, MD 21402 U.S.A

Steven G. Greenbaum and Krešimir J. Adamić

Physics Department  
Hunter College of CUNY  
New York, NY 10021 U.S.A.

Keywords: ion-conducting polymer; salt precipitation; NMR; DSC;  
poly(propylene oxide)



Accession For	
NTIS GRA&I	<input checked="checked" type="checkbox"/>
DTIC TAB	<input type="checkbox"/>
Unannounced	<input type="checkbox"/>
Justification	
By	
Distribution/	
Availability Codes	
Dist	Avail and/or Special
A-1	

### SYNOPSIS

DSC and electrical conductivity measurements of PPO complexed with NaI and KSCN are reported. In addition,  $^{23}\text{Na}$  NMR measurements of  $\text{PPO}_8\text{NaI}$ , both at ambient and elevated pressure (2.0 kbar) have been performed. The DSC data clearly indicate that the salt precipitates out of the complexes at about  $85^\circ\text{C}$  for NaI and  $60^\circ\text{C}$  for KSCN. These effects are manifested by a dramatic departure of the conductivity from VTF behaviour, and a relatively sharp drop in mobile Na concentration deduced from NMR measurements at somewhat elevated temperature ( $\sim 80^\circ\text{C}$ ). High pressure NMR linewidth measurements are consistent with a pressure-induced increase in glass transition temperature.

## INTRODUCTION

Poly(propylene oxide) (PPO) is known to form amorphous ion conducting complexes with alkali metal salts.<sup>1-3</sup> Previous studies of PPO complexed with  $\text{LiClO}_4$ <sup>2</sup> and  $\text{NaClO}_4$ <sup>3</sup> have shown that large scale segmental motion of the polymer chains is principally responsible for ionic transport, in general agreement with the results of a wide array of recent investigations. The studies in our laboratories<sup>2,3</sup> can be summarized briefly as follows. The electrical conductivity temperature dependence is best described by a VTF-type relation<sup>4</sup>

$$\sigma = A T^{-1/2} \exp[-E_a/k(T - T_0)] \quad (1)$$

where  $E_a$  is the apparent activation energy and  $T_0$  is the temperature of "zero configurational entropy", about 40-50 K below the glass transition temperature,  $T_g$ . The temperature dependence of the electrical relaxation time associated with the  $\sigma$ -relaxation which governs the glass to rubber transition in pure PPO can be described in an analogous manner. It has been shown that the activation energies for conductivity in the complexes and electrical relaxation in pure PPO are the same when one takes into account the different  $T_0$  values associated with each material. Similarly, activation volumes for conductivity derived from variable pressure data in the complexes and the  $\sigma$ -relaxation in PPO were shown to be the same in a given temperature interval relative to  $T_0$ .

<sup>23</sup>Na NMR studies in  $\text{PPO} \cdot \text{NaClO}_4$  have shown that: (1) generation of mobile ions is a weakly thermally activated process that accounts for only a minor contribution to the overall conductivity; (2) NMR signals associated with the mobile fraction of Na ions exhibit motional line-narrowing beginning in a small temperature interval above  $T_g$ . These results, taken together, demonstrate the importance of polymer chain mobility to ion transport, in general agreement with a wide array of recent investigations.

The present study concerns related work on  $\text{PPO}:\text{NaI}$  and  $\text{PPO}:\text{KSCN}$  complexes. In particular, it is observed that these materials

exhibit behaviour similar to that of previously investigated PPO complexes, however they become unstable at moderate temperatures ( $<100^{\circ}\text{C}$ ). As will be discussed, the instability is manifested ultimately by the separation of the salt from the polymer.

We have performed differential scanning calorimetry (DSC), electrical conductivity and  $^{23}\text{Na}$  nuclear magnetic resonance (NMR) measurements on  $\text{PPO}_8\text{NaI}$ . The NMR measurements were performed both at ambient pressure and at applied hydrostatic pressure up to 2 kbar (0.2 GPa). In addition, DSC and conductivity data for  $\text{PPO}_8\text{KSCN}$  are presented.

## EXPERIMENTAL

The host material studied was Parel 58 (Hercules, Inc.) elastomer which is a sulfur-vulcanizable copolymer of propylene oxide and allyl glycidyl ether. As the primary constituent is propylene oxide, the material will be referred to throughout this paper as PPO. The samples were prepared by solution casting using anhydrous methanol as the solvent and commercially obtained NaI, which was heated at  $100^{\circ}\text{C}$  in a vacuum oven overnight, as the salt. All procedures including loading of the samples into the various sample holders were carried out in a dry box; the sample for the NMR measurements was sealed in a glass tube under dry nitrogen. For the high pressure measurements, the sample was loaded into the rf coil in a  $\text{N}_2$  glove bag and then immersed in the pressure transmitting fluid (3M - Fluorinert) contained in the pressure cell. The details regarding the DSC, electrical conductivity and NMR equipment and techniques are given elsewhere.<sup>2,3</sup>

## RESULTS

The DSC results for  $\text{PPO}_8\text{NaI}$  are shown in Fig. 1. Results for uncomplexed PPO are included for comparison. It is clear that the complexed material is highly amorphous in that it exhibits a strong glass transition with a "central"  $T_g$  of about  $6^{\circ}\text{C}$ . (The "onset"  $T_g$  is about  $0^{\circ}\text{C}$  and the "end" is at about  $12^{\circ}\text{C}$ .) Consequently,  $T_g$  is about  $68^{\circ}\text{C}$  higher than for the uncomplexed material for which the



"central" glass transition temperature is about  $-62^{\circ}\text{C}$  as shown in Fig. 1c. An increase in  $T_g$  with the addition of salt to PPO is a well known phenomenon<sup>2</sup>.

In addition, in the DSC studies for  $\text{PPO}_8\text{NaI}$ , a strong, sharp endothermic event is observed at about  $100^{\circ}\text{C}$ . In order to obtain information concerning this feature, the material was annealed at  $175^{\circ}\text{C}$ , quenched to  $-140^{\circ}\text{C}$  as rapidly as possible in situ, and the DSC studies repeated. Typical results for the quenched material after annealing at temperatures above  $140^{\circ}\text{C}$  are shown in Fig. 1b. In all cases, a strong glass transition typical of uncomplexed PPO is observed. In addition, there is a high temperature exothermic event followed by an endotherm. Similar behavior has been observed for  $\text{PPO}_8\text{NaClO}_4$  where it was concluded that the high temperature endotherm is due to the salt coming out of the polymer.<sup>3</sup> The primary evidence is that only the glass transition due to uncomplexed PPO is observed after quenching from temperatures above that of the sharp endotherm. Further, the material exhibits the original behavior (Fig. 1a) after allowing the sample to sit at room temperature overnight, i.e. the salt redissolves in the polymer. Salt precipitation has been observed spectroscopically for PPO containing  $\text{NaSCN}$ .<sup>5</sup>

In order to gain further evidence for this effect, electrical conductivity studies were performed. (It was not possible to perform such studies for  $\text{PPO}_8\text{NaClO}_4$  as the salt precipitation temperature was outside the range of the conductivity apparatus.) The results are shown in Fig. 2. It is seen that the electrical conductivity begins to deviate from its lower temperature behavior at about  $85^{\circ}\text{C}$ . In order to demonstrate this more quantitatively, the data in the temperature range 280-355 K were analyzed with equation (1) with the adjustable parameters  $A$ ,  $E_a$ , and  $T_0$ . A non-linear least squares fit of eq. (1) to the data was carried out and the results are  $E_a = 0.093 \text{ eV}$ ,  $T_0 = 199.3 \text{ K}$ , and  $\log_{10} A [(\Omega\text{-cm})^{-1} \text{ K}^{1/2}] = -1.1$ . The RMS deviation in  $\log_{10} \sigma$  was 0.008. These best-fit values are close to those observed for other salts in PPO. However, they are not as reliable due to the limited temperature range covered, and further, the high temperature cut-off (where salt precipitation becomes

important) is merely an estimate. In fact, the value for  $T_0$  is about 80 K lower than the "central"  $T_g$ , which is a larger difference than expected.

A general feature of the  $^{23}\text{Na}$  NMR results is the coexistence of two separate lineshape components with substantially different spin-lattice relaxation times ( $T_1$ ) and linewidths. As in previous studies of similar complexes, the long- $T_1$  and broad component is attributed to bound Na species while the short- $T_1$  and narrow component arises from mobile  $\text{Na}^+$  ions.<sup>3</sup> The ratio of the narrow line to broad line intensities as a function of reciprocal temperature is plotted in Fig. 3. That the difference between the lowest temperature value and the maximum value (occurring just above room temperature) is only about a factor of ten is indicative of the relatively minor role that "carrier generation" plays in the overall conductivity, which changes by more than four orders of magnitude over the same temperature range. The salt precipitation is manifested as a sharp drop in mobile ion concentration above 80°C.

Figure 4 is a plot of  $^{23}\text{Na}$  resonance linewidth (full width at half maximum) as a function of temperature. The open symbols denote partially saturated resonances which correspond to the mobile sodium population. The solid symbols refer to the total (unsaturated) linewidth. As in previous work<sup>3</sup>, the linewidths of the mobile and bound Na's are nearly indistinguishable below  $T_g$ , only their  $T_1$  values are distinct. It is clear from the data that motional narrowing occurs above  $T_g$ , again in agreement with previous studies. The increase in linewidth above ~ 60°C is attributable to rapid spin-lattice relaxation ( $T_1 \sim 300 \mu\text{s}$ ) which introduces a lifetime broadening contributions to the linewidth.

The application of hydrostatic pressure (up to several kbar) has been shown to result in a decrease in conductivity of PPO complexes<sup>2,3</sup>. In order to obtain a better understanding of the mechanisms involved, we have performed some preliminary high pressure NMR measurements. Figure 5 displays  $^{23}\text{Na}$  absorption spectra (both lineshape components are present in each spectrum) at ~ 40°C, where motional narrowing effects are apparent. The bottom

spectrum corresponds to ambient pressure, while the top spectrum was acquired at 2.0 kbar (0.2 GPa). The effect of the applied pressure is to broaden the resonance by about 25% to approximately the linewidth of the sample at lower temperatures (below  $T_g$ ). This result is consistent with increases in  $T_g$  with pressure deduced from conductivity measurements<sup>2,3</sup>. It is not presently known whether these phenomena simply reflect the pressure dependence of  $T_g$ , or are indicative of more subtle ion-polymer interactions. High pressure DSC measurements are currently underway in order to determine directly the  $T_g$  pressure-dependence. Conductivity vs. pressure studies, which may shed light on the salt precipitation process, are also in progress.

Another example of this salt precipitation is evident upon viewing the data for  $\text{PPO}_8\text{KSCN}$ , shown in Figs. 6 and 7. For this material, the salt comes out of the polymer at a lower temperature, about 60°C as seen by a sharp endotherm at about 60°C in Fig. 6. That the material was complexed is shown by the single glass transition temperature at about -25°C. Once again, upon thermal treatment, the glass transition disappears with the appearance of an uncomplexed PPO glass transition. This material is interesting because the melting endotherms for the salt are at relatively low temperature as shown in Fig. 6a. As shown in Figs. 6b and 6c, similar endotherms are observed in the polymer after heating above 60°C. Since the salt precipitation occurs at a relatively low temperature, the effect on the electrical conductivity is quite dramatic as shown in Fig. 7.

## CONCLUSIONS

PPO complexed with NaI has been shown to exhibit the same general ion-conducting properties as other PPO-salt complexes at lower temperatures, whereas salt precipitation effects are observed in the former above ~ 85°C. The salt precipitation is manifested by (i) a relatively sharp endothermic "event" in the DSC, and subsequent observation of a pure PPO glass transition (after quenching); (ii) departure of the electrical conductivity from VTF-type behavior at elevated temperatures; (iii) a sharp drop in mobile

Na concentration, deduced from NMR measurements, above  $\sim 80^{\circ}\text{C}$ . PPO complexed with KSCN exhibits even more dramatic salt precipitation effects, as evidenced by corresponding features in the DSC and conductivity data occurring at a lower temperature ( $\sim 60^{\circ}\text{C}$ ) as well as observation of KSCN melting endotherms in the complex. Preliminary NMR measurements on  $\text{PPO}_8\text{NaI}$  at an applied hydrostatic pressure of 2.0 kbar (0.2 GPa) are consistent with a pressure-induced increase in  $T_g$ .

#### ACKNOWLEDGMENTS

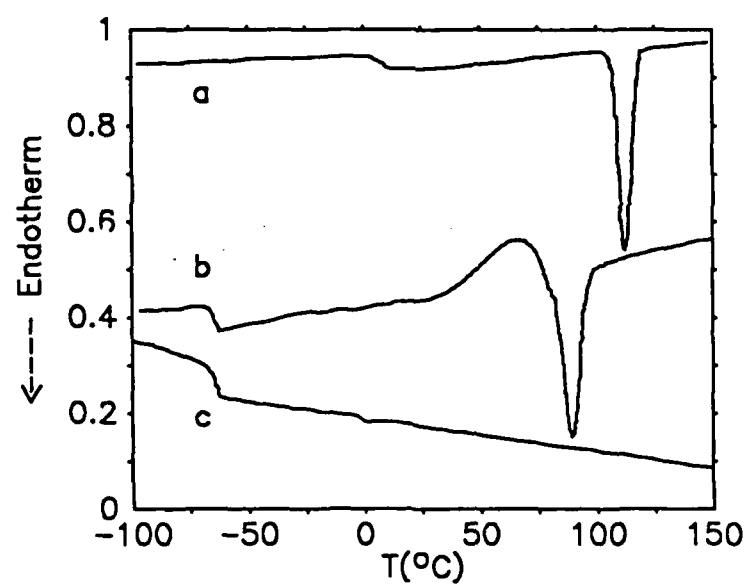
The authors would like to thank Hercules, Inc. for supplying the Parel 58 elastomer. The assistance of Ms. Meng Chiao, Ms. Gillian Reynolds, and Mr. Yiu Sun Pak with the NMR measurements and data analysis is gratefully acknowledged. This work was supported in part by the Office of Naval Research and the PSC-CUNY Research Award Program.

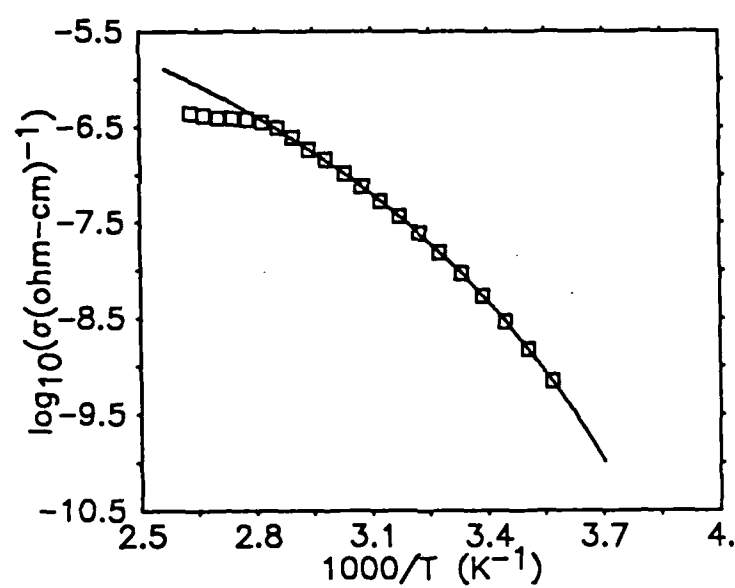
#### REFERENCES

- 1) Armand M., Chabagno M., and Ducloot M.J.; in: Fast Ion Transport in Solids, eds. Vashishta P., Mundy J.N., and Shenoy G.K. (North-Holland, Amsterdam, 1979), p. 131.
- 2) Fontanella J.J., Wintersgill M.C., Smith M.K., Semancik J., and Andeen C.G.; J. Appl. Phys., 1986, 60, 2665.
- 3) Greenbaum S.G., Pak Y.S., Wintersgill M.C., Fontanella J.J., Schultz J.W., and Andeen C.G.; J. Electrochem. Soc., in press.
- 4) Vogel, H., Physik Z., 1921, 22, 645; Tammann, V.G. and Hesse, Z., Anorg. Allg. Chem, 1926, 156, 245; Fulcher, G.S., J. Am. Ceram. Soc., 1925, 8, 339.
- 5) Teeters D. and Frech R.; Solid State Ionics, 1986, 18&19, 271.

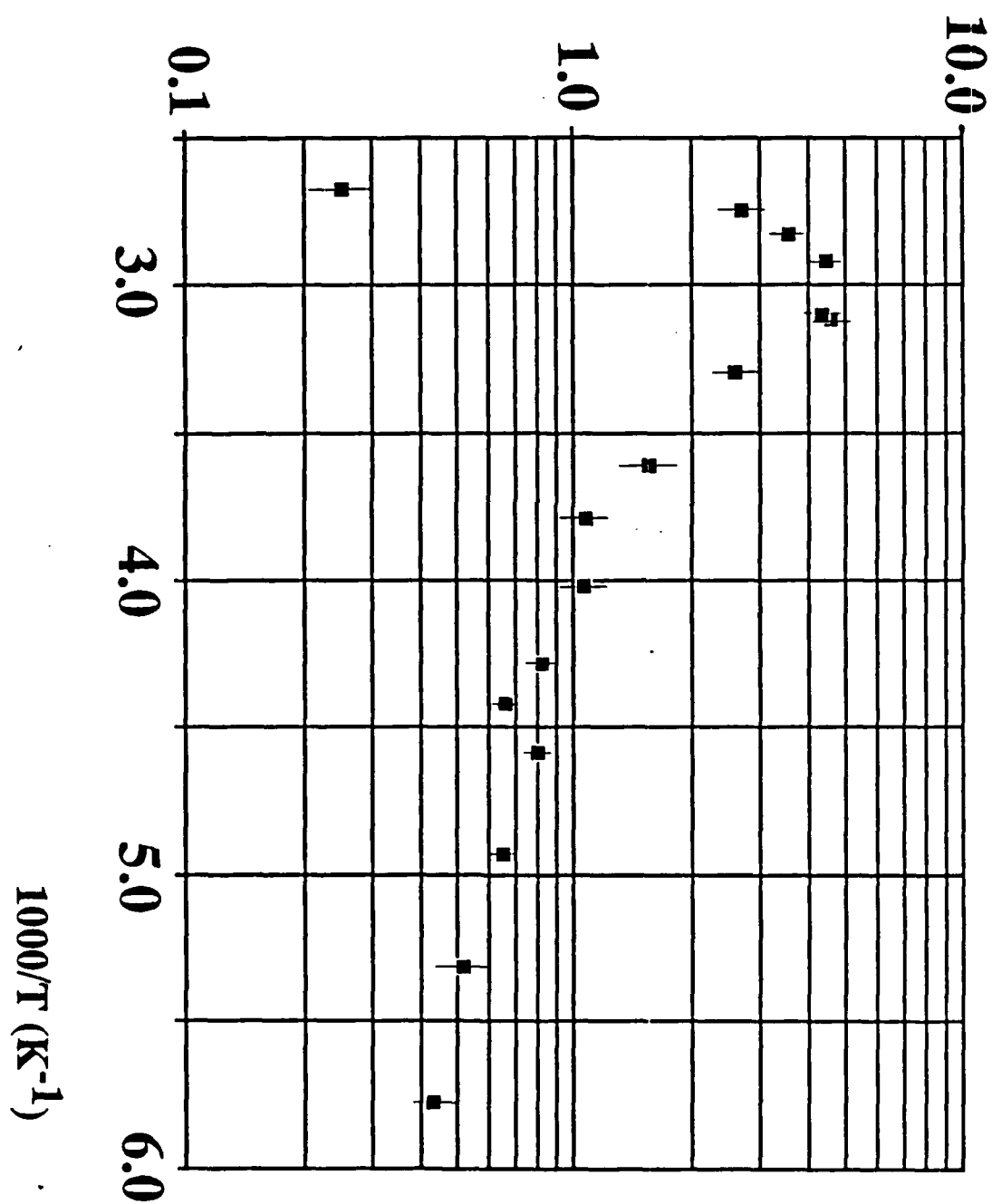
### FIGURE CAPTIONS

- Figure 1. DSC plot for a) uncomplexed PPO, b) as prepared  $\text{PPO}_8\text{NaI}$ , and c)  $\text{PPO}_8\text{NaI}$  after having been annealed at  $175^\circ\text{C}$  and quenched, in situ, to  $-140^\circ\text{C}$ . Scanning rate is 10 K/min.
- Figure 2. Arrhenius plot of the electrical conductivity data for  $\text{PPO}_8\text{NaI}$ . The squares correspond to the data and the solid line is the best fit VTF equation (equation 1).
- Figure 3. Arrhenius plot of  $^{23}\text{Na}$  narrow to broad line intensity ratios in  $\text{PPO}_8\text{NaI}$ .
- Figure 4.  $^{23}\text{Na}$  linewidth in  $\text{PPO}_8\text{NaI}$ . The solid symbols denote the total linewidth while the open symbols refer to partially saturated resonances, reflecting the presence of only the mobile sodium population.
- Figure 5.  $^{23}\text{Na}$  absorption spectrum in  $\text{PPO}_8\text{NaI}$  at  $40^\circ\text{C}$ . Bottom: ambient pressure; Top: applied hydrostatic pressure of 2 kbar ( $0.2 \text{ GPa}$ ).
- Figure 6. DSC plot for a) KSCN, b)  $\text{PPO}_8\text{KSCN}$ , c)  $\text{PPO}_8\text{KSCN}$  after having been annealed at  $200^\circ\text{C}$  and quenched, in situ, to  $-140^\circ\text{C}$ , d) uncomplexed PPO. Scanning rate is 10 K/min.
- Figure 7. Arrhenius plot of the electrical conductivity data for  $\text{PPO}_8\text{KSCN}$ . The solid line connects the data points.

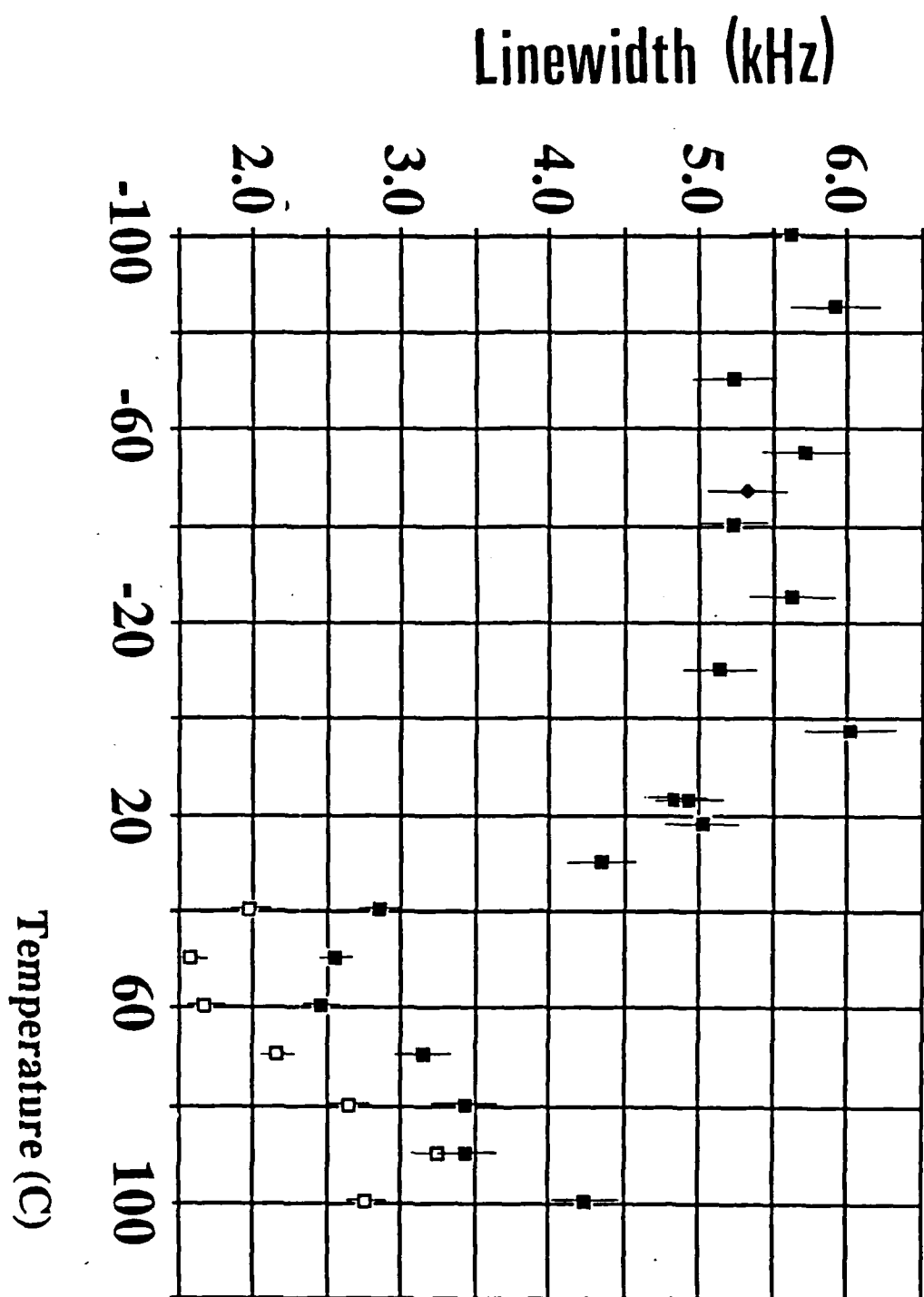


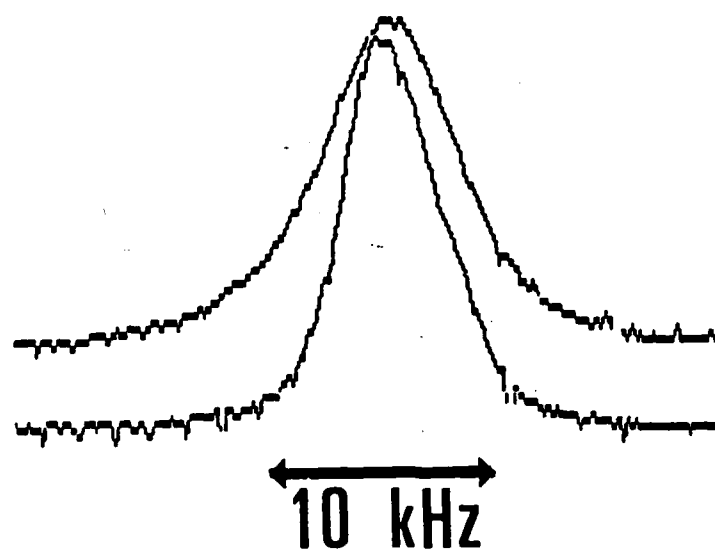


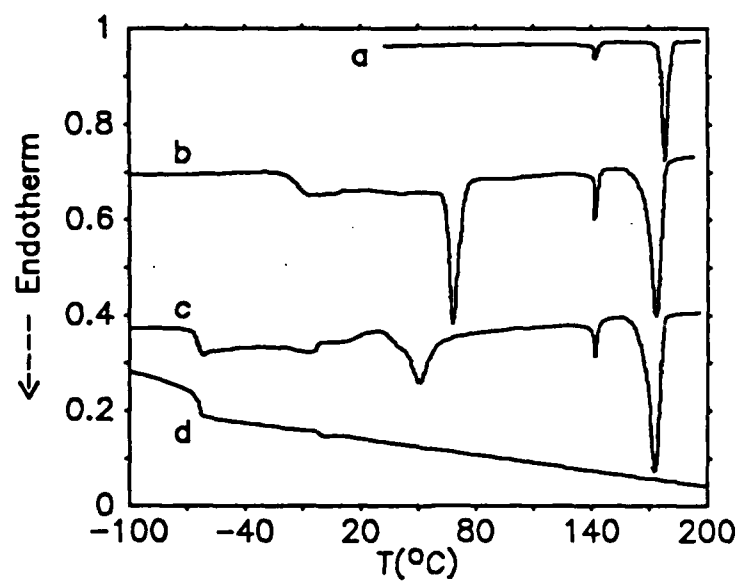
Relative intensity (N/B)











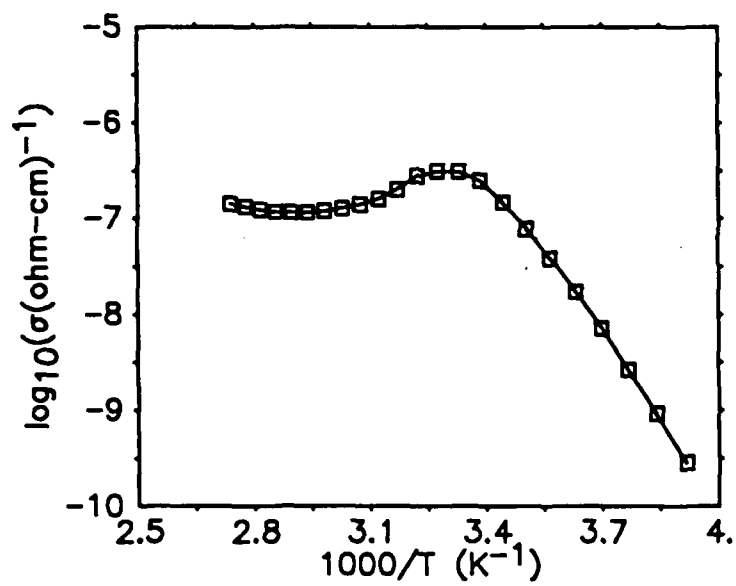


Fig. 7

TECHNICAL REPORT DISTRIBUTION LIST, GEN

	<u>No. Copies</u>		<u>No. Copies</u>
Office of Naval Research Attn: Code 1113 800 N. Quincy Street Arlington, Virginia 22217-5000	2	Dr. David Young Code 334 NORDA NSTL, Mississippi 39529	1
Dr. Bernard Douda Naval Weapons Support Center Code 50C Crane, Indiana 47522-5050	1	Naval Weapons Center Attn: Dr. Ron Atkins Chemistry Division China Lake, California 93555	1
Naval Civil Engineering Laboratory Attn: Dr. R. W. Drisko, Code L52 Port Hueneme, California 93401	1	Scientific Advisor Commandant of the Marine Corps Code RD-1 Washington, D.C. 20380	1
Defense Technical Information Center Building 5, Cameron Station Alexandria, Virginia 22314	12 high quality	U.S. Army Research Office Attn: CRD-AA-IP P.O. Box 12211 Research Triangle Park, NC 27709	1
DTNSRDC Attn: Dr. H. Singerman Applied Chemistry Division Annapolis, Maryland 21401	1	Mr. John Boyle Materials Branch Naval Ship Engineering Center Philadelphia, Pennsylvania 19112	1
Dr. William Tolles Superintendent Chemistry Division, Code 6100 Naval Research Laboratory Washington, D.C. 20375-5000	1	Naval Ocean Systems Center Attn: Dr. S. Yamamoto Marine Sciences Division San Diego, California 91232	1

ABSTRACTS DISTRIBUTION LIST, 359/627

Dr. Stanislaw Szpak  
Naval Ocean Systems Center  
Code 633, Bayside  
San Diego, California 95152

Dr. Gregory Farrington  
Department of Materials Science  
and Engineering  
University of Pennsylvania  
Philadelphia, Pennsylvania 19104

Dr. John Fontanella  
Department of Physics  
U.S. Naval Academy  
Annapolis, Maryland 21402-5062

Dr. Micha Tomkiewicz  
Department of Physics  
Brooklyn College  
Brooklyn, New York 11210

Dr. Lesser Blum  
Department of Physics  
University of Puerto Rico  
Rio Piedras, Puerto Rico 00931

Dr. Joseph Gordon, II  
IBM Corporation  
5600 Cottle Road  
San Jose, California 95193

Dr. Joel Harris  
Department of Chemistry  
University of Utah  
Salt Lake City, Utah 84112

Dr. J. O. Thomas  
University of Uppsala  
Institute of Chemistry  
Box 531 Baltimore, Maryland 21218  
S-751 21 Uppsala, Sweden

Dr. John Owen  
Department of Chemistry and  
Applied Chemistry  
University of Salford  
Salford M5 4WT UNITED KINGDOM

Dr. O. Staffsudd  
Department of Electrical Engineering  
University of California  
Los Angeles, California 90024

Dr. Boone Owens  
Department of Chemical Engineering  
and Materials Science  
University of Minnesota  
Minneapolis, Minnesota 55455

Dr. Johann A. Joebstl  
USA Mobility Equipment R&D Command  
DRDME-EC  
Fort Belvoir, Virginia 22060

Dr. Albert R. Landgrebe  
U.S. Department of Energy  
M.S. 6B025 Forrestal Building  
Washington, D.C. 20595

Dr. J. J. Brophy  
Department of Physics  
University of Utah  
Salt Lake City, Utah 84112

Dr. Charles Martin  
Department of Chemistry  
Texas A&M University  
College Station, Texas 77843

Dr. Milos Novotny  
Department of Chemistry  
Indiana University  
Bloomington, Indiana 47405

Dr. Mark A. McHugh  
Department of Chemical Engineering  
The Johns Hopkins University  
Baltimore, Maryland 21218

Dr. D. E. Irish  
Department of Chemistry  
University of Waterloo  
Waterloo, Ontario, Canada  
N2L 3G1

ABSTRACTS DISTRIBUTION LIST, 359/627

Dr. Martin Fleischmann  
Department of Chemistry  
University of Southampton  
Southampton SO9 5H UNITED KINGDOM

Dr. John Wilkes  
Department of the Air Force  
United States Air Force Academy  
Colorado Springs, Colorado 80840-6528

Dr. R. A. Osteryoung  
Department of Chemistry  
State University of New York  
Buffalo, New York 14214

Dr. Janet Osteryoung  
Department of Chemistry  
State University of New York  
Buffalo, New York 14214

Dr. A. J. Bard  
Department of Chemistry  
University of Texas  
Austin, Texas 78712

Dr. Steven Greenbaum  
Department of Physics and Astronomy  
Hunter College  
695 Park Avenue  
New York, New York 10021

Dr. Donald Sandstrom  
Boeing Aerospace Co.  
P.O. Box 3999  
Seattle, Washington 98124

Mr. James R. Moden  
Naval Underwater Systems Center  
Code 3632  
Newport, Rhode Island 02840

Dr. D. Rolison  
Naval Research Laboratory  
Code 6171  
Washington, D.C. 20375-5000

Dr. D. F. Shriver  
Department of Chemistry  
Northwestern University  
Evanston, Illinois 60201

Dr. Alan Bewick  
Department of Chemistry  
The University of Southampton  
Southampton, SO9 5NH UNITED KINGDOM

Dr. Edward Fletcher  
Department of Mechanical Engineering  
University of Minnesota  
Minneapolis, Minnesota 55455

Dr. Bruce Dunn  
Department of Engineering &  
Applied Science  
University of California  
Los Angeles, California 90024

Dr. Elton Cairns  
Energy & Environment Division  
Lawrence Berkeley Laboratory  
University of California  
Berkeley, California 94720

Dr. Richard Pollard  
Department of Chemical Engineering  
University of Houston  
Houston, Texas 77004

Dr. M. Philpott  
IBM Research Division  
Mail Stop K 33/801  
San Jose, California 95130-6099

Dr. Martha Greenblatt  
Department of Chemistry, P.O. Box 939  
Rutgers University  
Piscataway, New Jersey 08855-0939

Dr. Anthony Sammells  
Eltron Research Inc.  
4260 Westbrook Drive, Suite 111  
Aurora, Illinois 60505

Dr. C. A. Angell  
Department of Chemistry  
Purdue University  
West Lafayette, Indiana 47907

Dr. Thomas Davis  
Polymers Division  
National Bureau of Standards  
Gaithersburg, Maryland 20899

ABSTRACTS DISTRIBUTION LIST, 359/627

Dr. Manfred Breiter  
Institut für Technische Elektrochemie  
Technischen Universität Wien  
9 Getreidemarkt, 1160 Wien  
AUSTRIA

Dr. E. Yeager  
Department of Chemistry  
Case Western Reserve University  
Cleveland, Ohio 44106

Dr. R. Sutula  
The Electrochemistry Branch  
Naval Surface Weapons Center  
Silver Spring, Maryland 20910

Dr. R. A. Marcus  
Department of Chemistry  
California Institute of Technology  
Pasadena, California 91125

Dr. J. J. Auborn  
AT&T Bell Laboratories  
600 Mountain Avenue  
Murray Hill, New Jersey 07974

Dr. M. S. Wrighton  
Chemistry Department  
Massachusetts Institute  
of Technology  
Cambridge, Massachusetts 02139

Dr. B. Stanley Pons  
Department of Chemistry  
University of Utah  
Salt Lake City, Utah 84112

Dr. Bernard Spielvogel  
U.S. Army Research Office  
P.O. Box 12211  
Research Triangle Park, NC 27709

Dr. Mel Miles  
Code 3852  
Naval Weapons Center  
China Lake, California 93555

Dr. P. P. Schmidt  
Department of Chemistry  
Oakland University  
Rochester, Michigan 48063

Dr. Roger Belt  
Litton Industries Inc.  
Airtron Division  
Morris Plains, NJ 07950

Dr. Ulrich Stimming  
Department of Chemical Engineering  
Columbia University  
New York, NY 10027

Dr. Royce W. Murray  
Department of Chemistry  
University of North Carolina  
Chapel Hill, North Carolina 27514

Dr. Michael J. Weaver  
Department of Chemistry  
Purdue University  
West Lafayette, Indiana 47907

Dr. R. David Rauh  
EIC Laboratories, Inc.  
Norwood, Massachusetts 02062

Dr. Edward M. Eyring  
Department of Chemistry  
University of Utah  
Salt Lake City, UT 84112

Dr. M. M. Nicholson  
Electronics Research Center  
Rockwell International  
3370 Miraloma Avenue  
Anaheim, California

Dr. Nathan Lewis  
Department of Chemistry  
Stanford University  
Stanford, California 94305

Dr. Hector D. Abruna  
Department of Chemistry  
Cornell University  
Ithaca, New York 14853

Dr. A. B. P. Lever  
Chemistry Department  
York University  
Downsview, Ontario M3J 1P3



DL/1113/87/2

ABSTRACTS DISTRIBUTION LIST, 359/627

Dr. Henry S. White  
Department of Chemical Engineering  
and Materials Science  
151 Amundson Hall  
421 Washington Avenue, S.E.  
Minneapolis, Minnesota 55455

Dr. Daniel A. Buttry  
Department of Chemistry  
University of Wyoming  
Laramie, Wyoming 82071

Dr. W. R. Fawcett  
Department of Chemistry  
University of California  
Davis, California 95616

Dr. Peter M. Blonsky  
Eveready Battery Company, Inc.  
25225 Detroit Road, P.O. Box 45035  
Westlake, Ohio 44145

END

9-87

Dtic